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ON THE USE OF FLOW DOMINANCE IN COMPLEXITY MEASURES FOR FACILITY LAYOUT PROBLEMS

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ABSTRACT

Various authors propose the use of flow dominance in complexity ratings to evaluate the complexity of facilities layout problems, to determine the choice between computer algorithms and visual based methods for plant layout, and to decide on the particular layout configuration (line or process layout) to be installed. This paper critically examines past contributions and casts some serious doubts on the validity of the flow dominance concept and the related measures of layout complexity. It is shown that flow dominance does not serve its intended purpose and that the complexity rating factors suggested in the literature, not only show serious problems with regard to their interpretability, but are largely unusable. Finally, we elaborate on the future work needed in this problem area.

I. INTRODUCTION

The concept of flow dominance was introduced by Vollmann and Buffa (1966) as a measure of the extent to which the flow matrix (from-to chart or travel chart) shows "dominant" flow patterns. Flow dominance was defined as the coefficient of variation of the flow data, computed from the flow matrix elements as (100 x standard deviation/mean). The conclusion suggested was that a flow matrix which exhibits a coefficient of variation, i.e., a flow dominance, in excess of 200 percent is dominated by obvious flows and can be laid out by inspection or by using one of the so-called visual based methods for plant layout. Where dominance is not significant, i.e., the coefficient of variation is not in excess of 200 percent, they suggest the use of a computerized layout algorithm such as CRAFT (Armour and Buffa (1963)).

Since its introduction the flow dominance concept has been steadily attracting the attention of several researchers who elaborated on the possible use of flow dominance in complexity ratings to determine the choice between computer algorithms and visual based plant layout methods (Block (1977, 1979), Buffa (1976), Coleman (1977), Gupta and Deisenroth (1981), Lewis and Block (1980), Scriabin and Vergin (1981), Trybus and Hopkins (1980)), to determine the extent to which flow dominance and other complexity measures can affect the computational time of a branch-and-bound algorithm for the quadratic assignment problem (Mojena, Vollmann and Okamoto (1976)), and to decide on the particular layout configuration (line or process layout) to be installed (Aneke and Carrie (1983)). The importance of the various conflicting conclusions which have been drawn by these researchers, warrant a further investigation of the potential use of the flow dominance concept and the derived complexity measures.

In the next section we give the formal definition of flow dominance, elaborate on the computation of lower and upper bounds to the flow dominance value and discuss the implications of the various flow dominance calculations which found their way through the literature. In Section III we discuss the potential use of flow dominance in complexity rating factors. In particular the shortcomings of the complexity rating factor suggested by Block (1979) are critically examined. Due to these shortcomings, it would be infeasible to use the complexity measure for its intended purpose, which is to determine the choice between computer algorithms and visual based methods for plant layout. We conclude that section with a discussion of the idiosyncracies of the line dominance concept, suggested by Scriabin and Vergin (1981) in order to overcome the drawbacks of Block's complexity rating. In order to decide on the particular layout configuration (line or process layout) to be installed, Aneke and Carrie (1983) introduced the flow complexity parameter. In Section IV we show that, due to serious shortcomings, this flow complexity measure not only poses serious problems with regard to its interpretation, but is totally unusable. The important problems which remain to be solved in measuring the complexity of layout problems are the subject of Section V. Our conclusions are presented in the final section.

II. THE FLOW DOMINANCE CONCEPT

Most optimal and suboptimal process layout procedures explicitly or implicitly reduce the process layout problem to the well-known quadratic assignment problem with the basic objective of minimizing the total materials handling costs (Herroelen (1982)). As such most algorithms accept the flow matrix, also known as the from-to chart, the travel chart or the cross chart, as a basic part of their input requirements. The flow matrix contains numbers representing some measure of the material flow between facility locations (e.g. number of unit loads per time period, number of trips per time period, number of face-to-face contacts, etc.). Vollmann and Buffa (1966) suggested the coefficient of variation as a measure of flow dominance, i.e., as a measure of the extent to which a given flow matrix exhibits a dominant flow pattern. They assert that when such dominant flow patterns exist, the corresponding layout problems can easily be solved by inspection, without the need for a sophisticated computer algorithm.

1. The Vollmann-Buffa calculations

Although a formal mathematical definition was not given by Vollmann and Buffa (1966), the particular method used for computing the coefficient of variation can be traced from their discussion and from the comments made in Buffa (1968). The coefficient of variation, i.e., the standard deviation as a percent of the mean, is computed from "the data in the flow matrix by simply regarding each matrix element as an observation, following usual procedures from that point on". This implies that Vollmann and Buffa base their computations only on the flow matrix data (so not including the cost of materials flow or any other weighting factor) and include the zeroes on the diagonal of the flow matrix as regular observations. In addition, the flow matrices used in their original flow dominance calculations are not necessarily symmetric (in which case the matrix elements represent the sum of the flows between facility locations in both directions).

Using more formal arguments, it seems fair to state that Vollmann and Buffa have the following relationships in mind when they refer to flow dominance. If we let n denote the number of facilities and f_{ij} denote the flow between facilities i and j, then flow dominance, f, is given by

$$f = 100 \frac{s}{m} \tag{1}$$

where

$$m = \left(\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} \right) / n^2, \tag{2}$$

denotes the mean and the unbiased estimator of the standard deviation is given as

$$s = \left\{ \left[\sum_{i=1}^{n} \sum_{j=1}^{n} (f_{ij}-m)^2 \right] / \left[n^2-1 \right] \right\}^{1/2} \tag{3}$$

Vollmann and Buffa (1966) conducted a computational experiment on four example layout problems which, in combination with the reported flow dominance values, paved the way for many confusing and utmost conflicting papers, replies and rejoinders on the potential use of flow dominance and some derived complexity measures to determine the choice between computer algorithms and visual based layout methods (Block (1977, 1979), Buffa (1976b), Coleman (1977), Scriabin and Vergin (1975, 1976, 1981), Trybus and Hopkins (1980)). The four layout problems used in the experiment, which are denied a detailed investigation in their 1966 paper (Vollmann and Buffa (1966)), involve a 12-facility symmetric flow matrix example originally used by Hillier (1963), a 10-facility asymmetric flow matrix example (the "engineering office layout problem") described by Buffa (1976a), a 20-facility symmetric flow matrix example discussed by Armour and Buffa (1963), and a 22-facility asymmetric example (the "aerospace industry machine shop problem") used by Buffa, Armour and Vollmann (1964). Vollmann and Buffa (1966) analyzed the four layout matrices for flow dominance yielding the following coefficients of variation : 135 %, 201 %, 252 %, and 519 %. The four examples were laid out on an intuitive basis after inspection of the flow matrices upon which the resulting layouts were used as initial inputs to the well-known CRAFT-program. Since CRAFT was able to obtain a twelve percent improvement in the cost of the 135 % flow dominance problem, but was much less effective in the other three problems, they concluded that layout problems having flow matrix data with a coefficient of variation in excess of 200 % can probably be solved by inspection of the flow matrix or some other approximation technique, while those with lower flow dominances would benefit from a computer approach. This 200 % limit has subsequently been regarded as valid by some authors (Block (1977), Buffa (1976b)), and has been partially or completely rejected by others (Scriabin and Vergin (1981), Trybus and Hopkins (1980)). Given the extremely limited scope of the computational experiment, all this did obviously not come by surprise.

Apart from the weakness of the computational experiment, a close examination of the flow dominance calculations performed by Vollmann and Buffa, casts some serious doubts on the validity of the 200 % limit. First of all, our attempts to reproduce the flow dominance values for the four layout examples were not at all successful. Using Eqs. (1) - (3), the 10-facility problem yielded a flow dominance of 117 % instead of 135 %; for the 10-facility problem we obtained a value of 201.7 % comparable to the 201 % reported by Vollmann and Buffa (1966), while the 20-facility problem yielded a flow dominance of 251.2 % comparable to the reported 252 %. (We were unable to check the reported flow dominance of 519 % for the 22-facility problem, since the paper by Buffa, Armour and Vollmann (1964) only gives a partial extract of the original flow matrix).

In addition, it is interesting to note that the flow matrix for the 10-facility problem, somewhat responsable for the 200 % limit, is asymmetric, while the flow matrices for the 12- and 20-facility problems are symmetric about the diagonal. Apparently the matrix elements of a symmetric flow matrix represent the sum of the flows between facility locations in both directions, while in an asymmetric flow matrix the elements denote unidirectional flows (Hillier (1963)). The use of a symmetric flow matrix seems to be common practice. For example, most of the layout problems used as test examples in the computational experiments reported in the literature (e.g. the well-known set of problems used by Nugent et al. (1968)) have a symmetric flow matrix. Scriabin and Vergin (1981) argue against the use of an asymmetric flow matrix. According to these authors, the use of an asymmetric flow matrix would incorrectly imply that it is more "difficult" to design a layout with unequal flows in both directions than one with unidirected flows. There is no need to enter a debate on this matter; suffice it to say that consistency is required in the use of symmetric or asymmetric matrices for flow dominance computations. If the flow matrix for the 10-facility problem is made symmetric by adding the matrix to its transpose, the resulting flow dominance value to be reported by Vollmann and Buffa (1966) would have been 146.5 % and not 201.7 %, reducing the 200 % limit to a 146 % limit !

2. Flow dominance for a symmetric flow matrix

In their computational experiment to determine the extent to which flow dominance and other measures can affect the computational time of a branch-and-bound algorithm for the quadratic assignment problem, Mojena et al. (1976) define flow dominance on the lower triangle of a symmetric flow matrix :

$$f = \frac{s}{m} \tag{4}$$

where

$$m = \left(\sum_{i=2}^{n} \sum_{j=1}^{i-1} f_{ij} \right) / N \tag{5}$$

$$s = \left\{ \left[\sum_{i=2}^{n} \sum_{j=1}^{i-1} (f_{ij} - m)^2 \right] / [N-1] \right\}^{1/2} \tag{6}$$

and

n = number of facilities

f_{ij} = flow between facilities i and j

N = n(n-1)/2, number of items in the lower triangle of the symmetric flow matrix.

This procedure is clearly different from the one advocated by Vollmann and Buffa (1966). The coefficient of variation is now computed on the lower triangle of the symmetric flow matrix, the elements of which denote the sum of the flows in both directions between the facilities. In addition the zeroes on the main diagonal are ommitted from the calculations.

3. The inclusion of costs

Scriabin and Vergin (1981) contend that before attempting to solve any layout problem one would normally develop a symmetric flow-cost matrix, multiplying each flow by its associated cost per unit distance, then adding the resulting matrix to its transpose. They state that any measure of the problem's complexity should therefore be based on an analysis of that symmetric matrix. It is apparent from their calculations that they suggest to define flow dominance as

$$f = 100 \frac{s}{m} \tag{7}$$

where

$$m = \left(\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} \right) / n^2 \tag{8}$$

$$s = \left\{ \left[\sum_{i=1}^{n} \sum_{j=1}^{n} (f_{ij}-m)^2 \right] / n^2 \right\}^{1/2} \tag{9}$$

and

n = number of facilities in the symmetric flow-cost matrix

f_{ij} = flow-cost relationship between facilities i and j.

It should be stressed that Scriabin and Vergin use the biased estimator for s in Eq. (9).

The inclusion of cost is also implicitly suggested by Block (1977,1979) who defines f_{ij} as the "interdepartmental cost between departments i and j" in Block (1977) and as "the cost relationship between the ith and jth facilities" in Block (1979). Aneke and Carrie (1983) define the f_{ij} as the "data (e.g. flow, cost) relationship between the ith and jth facilities in a travel chart". The flow-cost matrix they refer to, however, is not necessarily symmetric. In other words, Block (1977, 1979) and Aneke and Carrie (1983) use the flow dominance definition given in Eqs. (1)-(3), with the proper flow-cost definition for the f_{ij}.

4. Upper and lower bounds to flow dominance

Block (1979) has recently formalized the observations already made by Vollmann and Buffa (1966) in establishing an upper and lower bound to flow dominance. The lower bound, f_{LB}, corresponds to the case where all the elements of the flow matrix (or the flow-cost matrix), except those on the principal diagonal, are equal and all the elements on the principal diagonal are equal to zero. In mathematical terms,

$$f_{ij} = a \qquad (i \neq j)$$
$$\quad = 0 \qquad \text{otherwise,}$$

which gives

$$f_{LB} = 100\, n \left[\frac{1}{(n^2-1)(n-1)}\right]^{1/2} \tag{10}$$

The lower bound f_{LB} is only dependent on the number of facilities.

The upper bound, f_{UB}, according to Block (1979) and Vollmann and Buffa (1966), corresponds to the case where

$$f_{ij} = a \qquad (j = i-1;\ i = 2,3, \ldots, n)$$
$$\quad = 0 \qquad \text{otherwise}$$

which gives

$$f_{UB} = 100\ n\ \left[\frac{n^2-n+1}{(n-1)(n^2-1)}\right]^{1/2} \tag{11}$$

In the context of plant layout Block's derivation of f_{UB} corresponds to the sequential flow of a fixed number going from the first facility to the second facility, ..., to the nth facility without any backtracking or cross-flow. In addition (see also Scriabin and Vergin (1981), f_{UB} is based on an asymmetric flow matrix. Where Block (1979) admits that f_{UB} is only a lower bound to the upper bound of flow dominance (altering any of the sequential flow values increases the flow dominance), Gupta and Deisenroth (1981) and Aneke and Carrie (1983) have shown that f_{UB} as given by Eq. (11) is not a true upper bound on flow dominance. Gupta and Deisenroth (1981), derive the true upper bound as

$$f_{UB} = 100\ n, \tag{12}$$

which obviously occurs for the situation where all elements of the flow (cost) matrix are zero except one.

5. Sensitivity of flow dominance values

Flow dominance, measured by the coefficient of variation based on any of the formulations discussed above, is very sensitive to changes in just one element of the flow matrix (or the flow-cost matrix). In order to illustrate this consider a four facility layout problem in which all flows are equal to 1. Applying Eq. (10), we obtain a flow dominance of f_{LB} = 59.63 %. If we replace one of the flows by a large flow, say 1000, then flow dominance as given by Eq. (1), is 395.36 %, almost equal to f_{UB} = 400 as given by Eq. (12). A change in only one matrix element, which in this case corresponds to the inclusion of one very large flow, has a dramatic effect on flow dominance. Similar conclusions have been obtained by Scriabin and Vergin (1981) and by Gupta and Deisenroth (1981). This extreme sensitivity of flow dominance already casts some serious doubts on the usefulness of the concept in establishing complexity measures for layout problems.

III. THE USE OF FLOW DOMINANCE IN COMPLEXITY RATINGS

Reaching the conclusion that the use of the 200 % flow dominance limit to determine the choice between computer algorithms and visual based methods may be an over-simplification - a conclusion which should be apparent also from our discussion so far - Block (1979) attempted to provide a more definite measure to determine problem complexity. Block defines his complexity rating factor, C_f, for a particular layout problem as follows :

$$C_f = 100\ (f_{UB} - f)\ /\ (f_{UB} - f_{LB}), \tag{13}$$

where

f = flow dominance obtained for the flow (cost) matrix by applying Eq. (1)

f_{UB} = flow dominance value computed by Eq. (11)

f_{LB} = flow dominance value computed by Eq. (10).

Block's measure is clearly intended to range between 0 % (corresponding to a problem with a flow dominance equal to f_{UB}; i.e., a simple problem) and 100 % (corresponding to a problem with a flow dominance equal to f_{LB}; i.e., a complex problem). As such, C_f is a function of flow dominance and the number of facilities since f_{UB} and f_{LB} are functions of the number of facilities only.

There are, however, several problems with regard to the interpretability of Block's complexity rating factor. As already observed by Trybus and

Hopkins (1980) and Gupta and Deisenroth (1981), a flow-cost matrix with all elements equal (except the ones on the main diagonal, which are all equal to zero) would correspond to an utmost difficult problem since C_f = 100 %. But in this case, all solutions are optimal as it is irrelevant where one facility is placed with respect to any other (obviously, always under the assumption that the objective is only to minimize materials handling cost). As such it is one of the simplest problems to solve by hand. In spite of this fact, Block's complexity rating assigns a value of maximum difficulty to this particular case. As such the measure fails to recognize the possible fact that layout problems become easier for humans to solve as flow dominance approaches zero.

Gupta and Deisenroth (1980), and also Scriabin and Vergin (1981), also mention another drawback of Block's measure : it can assume negative values. In combination with the fact that Block's upper bound has been shown to be incorrect, this possibility makes the complexity rating factor unusable.

Scriabin and Vergin (1981) contend that the coefficient of variation of flows, or flow dominance, is certainly not a good indicator of the presence of "line dominance" as originally intended by Vollmann and Buffa. They simply define line dominance as the extent to which a layout problem contains assembly line-like flow data. Line dominance is high in a problem with only a few long job routes, while a problem with many very short job routes has low line dominance. They fail, however, to propose a precise measure of line dominance and simply suggest that, until a better measure of line dominance is developed, comparisons of procedures for facility layout should be based on their performance on real problems with known line dominance, or on problems with artificially generated flow-cost matrices containing prespecified levels of line dominance.

IV. FLOW COMPLEXITY AS A SUITABILITY INDEX FOR FLOW LINE SYSTEMS

Recently Aneke and Carrie (1983) introduced a new parameter, the flow complexity, which according to the authors, more effectively measures the complexity of flow and which is intended to provide an indication of when to set up a flow line for a given flow or flow-cost matrix. The flow complexity parameter, F_c, is intended to assume values between 0 and 1. When $F_c = 0$, the flow matrix data would indicate that the most suitable layout is a pure flow line, when $F_c = 1$, a process layout would be more appropriate. Intermediate values would imply the appropriateness of intermediate layout types such as group technology cells.

Flow complexity, F_c, is defined for a particular problem as

$$F_c = \frac{f_s - f}{f_s - f_r}, \qquad (12)$$

where

f = flow dominance computed on the original flow (cost) matrix using Eqs. (1)-(3).

f_s = flow dominance computed by Eqs. (1)-(3) for an equivalent sequential flow (cost) matrix.

f_r = flow dominance computed by Eqs. (1)-(3) for an equivalent random flow matrix.

Aneke and Carrie (1983) now argue that when the original flow matrix exhibits a sequential flow as in a simple flow line, the flow dominance, f, of the original raw data becomes equal to that of the equivalent sequential flow, i.e., $f = f_s$ and $F_c = 0$. But when the flow in the original matrix is completely random (all the matrix cells are filled, except the zeroes on the main diagonal), the flow dominance, f, of the original raw data approximates that of an equivalent random flow, i.e., $f = f_r$ and $F_c = 1$. Therefore, they conclude that the flow complexity, F_c, must lie between 0 and 1. An F_c-value equal to zero implies that the flow data are suitable for a simple flow line, while $F_c = 1$ implies that a process layout is more suitable.

Aneke and Carrie (1983) obtain the equivalent sequential flow matrix from the original flow matrix by "making the flow sequential but using the average value of each row's non-zero entries in the travel chart for that row". Similarly, an equivalent random flow matrix is obtained "by making flow completely random but using the average value of each row's non-zero entries in the travel chart for that row".

In order to illustrate the procedure for computing the flow complexity, consider the following original flow (cost) matrix :

$$M_o = \begin{bmatrix} 0 & 1000 & 1 \\ 0 & 0 & 10 \\ 0 & 0 & 0 \end{bmatrix}$$

Flow dominance, f, computed according to Eqs. (1)-(3), equals 296.34 %. The matrix M_o is not sequential. Following the suggestions made by Aneke and Carrie (1983), it is made sequential using the average value of each row's non-zero entries, yielding the equivalent sequential flow matrix

$$M_s = \begin{bmatrix} 0 & 500.5 & 0 \\ 0 & 0 & 10 \\ 0 & 0 & 0 \end{bmatrix}$$

The flow dominance, f_s, also computed according to Eqs. (1)-(3), equals 293.45 %. As can be seen $f_s < f$ in this example; a possibility which was clearly not recognized by Aneke and Carrie (1983). The original matrix, M_o, can be transformed into an equivalent random matrix again by using the average value of each row's non-zero entries. This yields the equivalent random flow matrix

$$M_r = \begin{bmatrix} 0 & 500.5 & 500.5 \\ 10 & 0 & 10 \\ 0 & 0 & 0 \end{bmatrix}$$

If we now apply Eqs. (1)-(3) on this matrix, we obtain a flow dominance value $f_r = 193.5$ %. Substitution of the flow dominance values obtained into Eq. (12) yields

$$F_c = \frac{293.45 - 296.34}{293.45 - 193.5} = -0.029,$$

clearly a negative value. This simple example shows that the flow complexity, F_c, suffers from the same drawback as Block's measure discussed in the previous section. The fact that F_c may assume negative values makes it uninterpretable and useless for its intended purpose, which is to distinguish the choice between a pure flow line at one extreme and a pure job-shop at the other.

A further indication of the fact that the flow complexity measure does not serve its basic purpose can be obtained from a simple look at the following flow matrix :

$$M_o = \begin{bmatrix} 0 & 1000 & 1 & 0 \\ 2 & 0 & 500 & 0 \\ 0 & 1 & 0 & 750 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

The flow dominance (Eqs. (1)-(3)) for this asymmetric matrix (the asymmetric case is clearly used by Aneke and Carrie to elaborate on the equivalent random flow matrix) is easily obtained as $f = 224.1$ %. Following the authors' arguments, the equivalent sequential flow matrix yields an $f_s = 224.51$ %, while the flow dominance for the equivalent random flow matrix equals $f_r = 98.44$ %. As a result $F_c = 0.0032 \simeq 0$ which clearly asks for a sequential flow line with major flow transfers from facility 1 to facility 2, to facility 3, to facility 4. Obviously, any simple rearrangement of the flows within the same row of the matrix has no effect on the F_c-value. All the different flow matrices so obtained, would have the same flow complexity, and would ask for the same physical flow line layout. The fact that this may lead to utmost strange situations is easily illustrated by looking at the following matrix

$$M_1 = \begin{bmatrix} 0 & 1000 & 1 & 0 \\ 2 & 0 & 500 & 0 \\ 750 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

This matrix is obtained from M_o by simply rearranging the elements in the third row and has the same $F_c = 0.0032$. As can be seen facility 4 has no associated flows, and looses any physical meaning. In addition the major flows now run in a circular fashion from facility 1 to facility 2, to facility 3. As Aneke and Carrie (1983) admit, their flow complexity measure collapses in all situations where backtracking type of flows occur.

V. THE MEASUREMENT OF LAYOUT PROBLEM COMPLEXITY

In the previous sections we critically examined the previous research efforts which in one way or another elaborate on the potential use of the flow dominance concept and derived complexity ratings to measure the complexity of a plant layout problem. The intended use of such a measure seems to be three-fold : (a) to determine the choice between computer algorithms and so-called visual based plant layout methods, (b) to predict the processing time requirements for a particular layout algorithm, and (c) to decide on the particular layout configuration to be installed. Our arguments should have made it clear that flow dominance alone, or in combination with the derived complexity ratings, certainly cannot serve its intended use. In addition, we have some serious doubts on the validity as such of possible use (a) and (c) stated above.

The first intended use, making the choice between computer algorithms and visual based plant layout methods, is to be considered as totally misplaced. Bringing the computer in competition with human beings is clear nonsense from the outset. The visual based plant layout methods, the "traditional industrial engineering type procedures" as they are called by Scriabin and Vergin (1975), are never clearly defined. The so-called computer algorithms included in the reported experiments are virtually all of the CRAFT-type, the serious drawbacks of which are fully discussed elsewhere (Herroelen (1981)). The severe limitations and the narrow-minded character of the many existing computerized layout algorithms are discussed in Herroelen (1977, 1982). They are commonly understood and are not retaken here. Using flow complexity measures to decide on the particular layout configuration to be installed (objective (c) above), is a mere neglect of the many complexities involved in designing a plant layout and materials handling system, as clarified by our arguments made in the previous section.

The measurement of layout problem complexity with (a) the intention to predict the processing time requirements for a particular computerized layout algorithm, and (b) the purpose of comparing two (or more) proposed computerized layout algorithms, is an important and difficult issue. Evidently, a choice between proposed algorithms, or the determination of the computational efficiency of a particular algorithm, would be greatly facilitated if there exists a measure of layout problem complexity. This would eliminate any possible bias in the conclusions regarding the efficiency of a particular algorithm relative to others by ensuring that the algorithm is evaluated at several points in the "range of complexity". The issue then is to isolate the factors that determine the computing effort and to achieve a calibration of the scale that characterizes such effort.

It has long been recognized in many problem areas that the computational requirements of a particular algorithm, is a function not only of the size of a problem, but also of the nature of the input data. Elmaghraby and Herroelen (1980) elaborate on this issue in the context of activity networks, Mojena et al. (1976) investigate the same issue in the context of the plant layout problem.

The computational experiment conducted by Mojena et al. (1976) was an attempt to determine the extent to which the nature of the input data (the flow-cost matrix) - measured by flow dominance and other predictor variables - can affect the computational time of a branch-and-bound algorithm used to solve the process layout problem formulated as a quadratic assignment problem (It should be mentioned that the quadratic assignment problem formulation is only one of the many possible layout problem formulations (Herroelen (1981, 1982)). They found that regression models based on twenty-two initial measures of the flow matrix were poor predictors of computational time, although they did find that flow dominance, measured by Eqs. (4)-(6), and two other related variables significantly discriminated among groups of problems requiring low, medium or high amounts of computing effort.

Careful study of the previous research efforts discussed in the previous sections, impels us to state that the layout complexity issue is in desperate need of further research. This research should take into account the many fundamental questions raised earlier (Elmaghraby and Herroelen (1980)) such as (a) what is the precise use of the complexity measure ?, (b) is the measure of layout complexity a quality possessed by the layout problem (e.g. the flow-cost data) or by the (analytical) procedures used in the analysis of the problem, i.e., is "complexity" an inherent property of the layout problem, or is it necessarily confounded by the procedure used in the analysis ?, (c) is the complexity measured by a vector of quantities, and if so, what is the corresponding scale of the measure ? So far, the literature is conspiciously void of any answers in this respect.

VI. CONCLUSIONS

The importance of the utmost conflicting conclusions drawn by previous research on the potential use of flow dominance in complexity measures for facility layout problems warranted a further investigation of this issue.

As for the flow dominance concept itself our findings suggest that extreme care must be taken in its use. The concept has been defined by many authors in many different ambiguous, often conflicting ways. Although flow dominance is generally measured by the coefficient of variation, detailed calculations are sometimes made on a flow matrix or on a flow-cost matrix, which has been made symmetric or not. Some authors include the zeroes on the matrix diagonal, others do not. Upper and lower bounds are often unprecisely defined. Flow dominance values heavily depend on small variations in the matrix elements. All those factors cast some serious doubts on the usefulness of the flow dominance concept as such.

The derived complexity measures - the 200 % limit established by Vollmann and Buffa, Block's complexity rating factor, the line dominance concept suggested by Scriabin and Vergin, and the flow complexity parameter suggested by Aneke and Carrie - all show some serious drawbacks, errors or false interpretations which make them unusable for their intended purpose.

This purpose, the measurement of layout problem complexity, has been shown to be still an unresolved utmost difficult problem issue. It is hoped that the various arguments given throughout this paper would provide some help in the extensive future work still needed in the area of defining complexity measures for facilities layout problems.

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